

MEXICO

Working paper containing a list of the documents of the Committee on Disarmament relating to the Treaty for the Prohibition of Nuclear Weapons in Latin America (Treaty of Tlatelolco) and of the statements by the Mexican delegation dealing wholly or partially with that treaty

I. Documents

<u>Symbol</u>	<u>Title</u>	<u>Date</u>
ENDX/186	Final Act of the fourth session of the Preparatory Commission for the Denuclearization of Latin America	21 February 1967
ENDX/241	Mexico. Establishment of nuclear-free zones. Working document	24 March 1969
CCD/268	Mexico. Report on the First Session of the General Conference of the Agency for the Prohibition of Nuclear Weapons in Latin America (OPANAL)	15 September 1969
CCI/241/ Add.1*	Mexico. Establishment of nuclear-free zones. Working document. Addendum	2 March 1970
CCI/342	Mexico. Working paper on some basic facts relating to the Treaty for the Prohibition of Nuclear Weapons in Latin America (Treaty of Tlatelolco) and its Additional Protocol II . . .	19 August 1971
CCD/358	Mexico. Letter dated 2 March 1972 from the Representative of Mexico to the Special Representative of the Secretary-General of the United Nations	2 March 1972

II. Statements by the Mexican delegation

<u>Date</u>	<u>Record</u>	<u>Paragraphs</u>
1967 21 February	ENDC/PV.287	47-77
21 March	ENDC/PV.295	2-24
18 May	ENDC/PV.297	51-55
19 September	ENDC/PV.331	2-26
1968 15 February	ENDC/PV.365	2-13
6 March	ENDC/PV.374	2-25
13 August	ENDC/PV.389	36-61
1969 10 April	ENDC/PV.402	2-39
29 April	ENDC/PV.407	24-25
3 July	ENDC/PV.416	42-49
9 September	ENDC/PV.435	2-7
30 September	ENDC/PV.448	42-54 and 97
1970 17 February	CCD/PV.449	61-99
26 February	CCD/PV.453	31-46
2 April	CCD/PV.461	38-40
1971 23 February	CCD/PV.495	71-73
22 April	CCD/PV.510	75-78
13 May	CCD/PV.516	58
27 July	CCD/PV.524	46-48
19 August	CCD/PV.531	25-31

CONFERENCE OF THE COMMITTEE ON DISARMAMENT

CCD/360

20 March 1972

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UNITED STATES OF AMERICA

Work Program regarding negotiations on prohibition of chemical weapons

I. INTRODUCTION

This paper sets forth some of the considerations that are relevant to the question of prohibition of chemical weapons. It deals primarily with lethal chemical warfare agents. The paper does not attempt to treat all of the many factors which we or others may feel are important with respect to these agents or offer final judgements on those questions that are discussed. The delegation hopes that the material presented will stimulate further discussion and assist the Committee towards reaching a consensus regarding those considerations that are important to successful negotiations.

II. SCOPE

This section (A) sets forth major categories of types of agents and precursors describing a number of factors which appear to the US delegation relevant to their consideration in the context of arms limitation, (B) describes possible ways of defining substances that might be controlled, and (C) sets forth and discusses classes of activities pertaining to chemical weapons programs together with relevant arms limitation considerations.

A. Major categories of substances related to chemical warfare include the following:

1. Single-purpose agents. These agents have no large-scale uses except in chemical warfare. Modern agents in this category, such as organophosphorus compounds, are extremely toxic. Some older agents, which caused a number of deaths in World War I, also fall into the "single-purpose" category.

2. "Dual-purpose" agents are chemicals which are commonly used for civilian purposes, but which might also be used as CW agents. Phosgene, chlorine, and hydrogen cyanide are well-known examples of substances in this category and were

utilized widely in the first World War. The extent of the civilian uses of these agents was described in a working paper (CCD/283) submitted earlier by the US delegation.

3. Precursors. Intermediates of modern agents may or may not have civilian applications. Phosphorus trichloride, for example, a key precursor in the production of organophosphorus nerve agents, is widely used as an intermediate in the manufacture of pesticides and plasticizers. Under present conditions, agent intermediates do not assume immediate military significance until processed further into an agent, but binary devices, by using agent intermediates as weapons components, could blur this distinction.

B. Definitions of Controlled Substances

The following general criteria offer various possibilities for defining chemical substances which might be used for chemical warfare:

1. General Toxicity Standard. Modern lethal agents are in general much more toxic to humans than are pesticides or other chemicals used in the civilian sector. A standard related to the toxicity of present-day nerve agents would exclude, for all practical purposes, chemicals which have civilian uses. However, allowance should be made for the fact that a number of super-toxic compounds have legitimate medical applications. If a toxicity standard were adopted it might be necessary to provide for a uniform laboratory method of determining the toxicity of a compound. The kind of animals to be used, their number and weight, the method of application of the chemical, and extrapolation of effects to humans, are among the factors which would have to be dealt with. Questions regarding the application of a toxicity standard might be referred to an international consultative body or some other appropriate international body.

2. Identification of Specific Agents. Many chemical substances which have been used in warfare or developed for weapons purposes are generally known. Although a comprehensive list of these known agents by name and specific structural formula might include the majority of agents in current arsenals, there is no way at present to know whether such a list would include all the major agents in the arsenals of states or under development.

3. General Structural Formula. All presently identified nerve agents are organophosphorus compounds which exert their toxic effect by inhibition of the enzyme acetylcholinesterase. Considerable information is available on the relationship between chemical structure and ability to inhibit acetylcholinesterase. A general structural formula might be developed which would describe the spectrum of organophosphorus compounds which could be used as lethal agents but would not include compounds used as pesticides. One possibility is the formula presented in CCD/320 by the delegation of the Netherlands.

4. Criterion Based on Purpose. The Biological Weapons Convention relies on a general formulation which prohibits agents "of types and in quantities that have no justification for prophylactic, protective or other peaceful purposes". This definition is both comprehensive and simple. Such a definition by itself, however, could be insufficiently precise for effective application to chemicals which are produced in extremely large quantities for peaceful purposes.

5. Combination of Methods. Having various possible prohibitions in mind, the Committee might consider what combination or combinations of criteria could be appropriate. The advantages might be weighed of using a purpose criterion, accompanied by one or more of the other forms of definition described above. If differing prohibitions were to be considered for various categories of agents, definitions would be needed which could distinguish such categories from one another. For example, with respect to prohibitions covering the most lethal types of agents, a definition might include, in addition to a purpose criterion, reference to structural formulas of known agents and specification of toxicity levels. Binary components, however, may not be readily distinguishable from many industrial chemicals either by their structural formula or toxicity. If such intermediates were to be considered, because of their potential military importance, for specific prohibitions, it might be desirable to consider a definition that was based on the

purpose criterion and a list of known substances. There are, of course, advantages and disadvantages to all of the various possible definitions and their combinations, which should be carefully considered by the Committee as it moves forward in its work on questions concerning CW prohibitions.

6. Maintaining Effective Definitions. The Committee might consider ways in which definitions could be kept current. Examples of possible technological developments which could affect the adequacy of definitions in future circumstances are:

- (a) Development of very toxic chemicals with non-military uses;
- (b) Development of binary weapons with "dual-purpose" chemical components;
- (c) Development of non-military uses for substances similar to present nerve agents;
- (d) Development of chemical compounds which have potential military utility but which do not clearly meet traditional criteria for determining controlled substances. In view of these possibilities, consideration might be given to the most appropriate means for continuing or periodic future consultations to help insure that the scope of substances to be controlled remains effectively defined, with updating as necessary.

C. Scope of Activities Which Might Be Controlled

The Committee should give consideration to the various classes of activities pertaining to chemical weapons programs together with relevant arms limitation factors.

1. Production of Agents is a key element in acquiring and, over the long run, in maintaining a chemical warfare capability. The current process of manufacture of modern lethal agents is a sophisticated one carried out in highly specialized facilities. These characteristics give rise to important considerations bearing on the question of nerve agent production controls:

(a) Initiating nerve agent production is a complex task. Considerable time is required to construct a new agent plant, convert another chemical facility to agent production, or even to reactivate an agent plant which has been shut down for more than a short period. The engineering difficulties which must be overcome are considerable. The cost of establishing a nerve agent manufacturing facility of the type used in the past is many times greater than for a production facility for commercial chemicals. These considerations may not be fully applicable in the case of production of components for binary weapons.

(b) While it may be reasonable to assume that there are relatively few chemical facilities which might be used at the present time to make organophosphorus chemical warfare agents, information is insufficient to determine which facilities in fact have this capability and have been engaged in agent production.

In the case of nerve agent production facilities, possibilities for demilitarization range from closing or "mothballing" plants to conversion or destruction. Measures which might be useful in ensuring that required actions were taken are discussed below in the verification section.

2. Production of Weapons

(a) Chemical munitions manufacture uses substantially the same type of metal-processing facilities used to make casings for conventional weapons. Filling of munitions with agent, on the other hand, characteristically is a highly specialized process carried out under stringent safety and security controls. The filling of chemical munitions with nerve agent would normally be carried out at or near the agent production facility, where appropriate conditions for handling highly toxic materials would already exist. This would be a lesser consideration in the filling of munitions using less toxic materials such as chlorine, phosgene or possible components of binary weapons.

(b) In considering possible approaches to prohibiting production of chemical weapons, the question of munitions might assume varying importance depending on the nature of the agents being utilized:

(i) Dual-Purpose Agents. A great many countries would, of course, continue to possess production facilities for, and large quantities of, such chemicals as chlorine and phosgene for peaceful industrial uses after any chemical weapons agreement. Such production facilities, or, current stocks, could be utilized at anytime for making weapons. Thus the activity which it seems most relevant to restrict in this area would be production of munitions rather than production of agents.

(ii) Nerve Agents. On the other hand, in the case of known nerve agent munitions, the agents themselves do not have large-scale peaceful uses, and their possession in any quantity, even when not filled in munitions, has military significance. Thus, controls affecting production of agents would appear to be of particular importance in connexion with such weapons as those using nerve agents.

3. Stockpiling. Possession of stocks of chemical weapons is essential to maintenance of an immediate chemical capability. While there is evidence which suggests the existence of substantial quantities of chemical arms in present day arsenals of several nations, storage of chemical weapons by its nature is not a readily identifiable activity. Several considerations seem pertinent in relation to stockpiling:

(a) There is general uncertainty over the size and composition of chemical weapons stocks in existence.

(b) A capability to retaliate promptly in kind to a chemical attack is one deterrent against initiation of chemical warfare.

(c) Destruction or demilitarization of stocks, given the toxic nature of modern agents, requires time-consuming and carefully controlled processing under stringent safety precautions. To ensure that none of the toxic agent escapes into the environment, a destruction facility must be operated under the principle of "total containment". Another major concern is the disposal of the end-products of the agent destruction. These end-products, while relatively non-toxic in themselves, might have a serious adverse effect if introduced into the environment in large quantities.

4. Research and Development

(a) Research. Certain lethal agents were an accidental by-product of industrial insecticide research conducted in civilian laboratories. It may be difficult to tell from the nature of research on toxic substances whether or not such research is part of a military programme. It may also be difficult to distinguish many aspects of research for offensive purposes from research for defensive or prophylactic purposes. At the same time, it is possible that a number of countries will attach importance to the continuation of research for defensive purposes.

(b) Development of promising CW agents and of means for disseminating them are explicitly military activities and go beyond the stage necessary for design of defensive measures. However, development, like research, is an activity of low visibility.

III. VERIFICATION

The Committee faces a number of important questions with respect to possible means of verification, both national and international. This section sets forth a number of considerations (A) on the relationship between the scope of prohibitions and verification, and (B) regarding the feasibility of possible specific verification elements such as (1) seals and monitoring devices, (2) information exchange, (3) declarations, (4) remote sensing devices, (5) inspection visits, and (6) monitoring of imports and shipments of certain specific materials.

A. Relationship Between Verification and Scope

Various possible combinations of CW prohibitions would be likely, in order to be effective, to require various measures of verification. Comprehensive prohibitions would, by definition, most completely limit chemical warfare capabilities. Moreover, comprehensive prohibitions, by covering many aspects of CW activities, would tend to reinforce each other. On the other hand, there may be some factors which would warrant the Committee's consideration of the relative merits of a phased approach in which some activities are prohibited initially and other activities at subsequent stages. For example, a simultaneous prohibition of production of certain agents or weapons, together with a requirement for complete destruction of any existing stocks of those agents or weapons, might require a higher degree of

assurance of compliance than if prohibitions were placed initially on production alone. As indicated earlier, possession of a retaliatory CW capability has been generally considered to provide one deterrent to the first-use of chemical weapons by others. A state possessing chemical weapons could feel that it required a very high degree of assurance that others would be taking the same steps it was to take, before agreeing to prohibitions which, when implemented, would leave it with no ability to retaliate promptly. Thus, one possible way some states might be satisfied with a somewhat lower level of initial assurance would be if the disarmament process took place in stages, that is, in the example under discussion, if production of certain classes of agents or weapons were prohibited initially while destruction of stockpiles were to take place in a subsequent stage.

B. Verification Elements

1. Seals and Monitoring Devices. The possibility exists of assuring that CW activity does not take place at "mothballed" facilities through the use of seals or monitoring devices of the types which have been studied in connexion with nuclear safeguards. This possibility has particular relevance with respect to a phased process in which CW production facilities are shut down but not initially dismantled. During the last session of the CCD, the delegation of the United States submitted a working paper (CCD/332) which describes the nature and possible utility of sealing and monitoring devices.

2. Information Exchange. Given the complexity, and the prospects for growth and change in the chemical industry throughout the world, provisions for information exchange might play a useful role in verifying chemical weapons limitations. Consideration might be given in the Committee to the types of information which would be helpful. Possibilities might include information regarding: (a) quantity, types, and uses of organophosphorus products; (b) quantity, types, and uses of dual purpose chemicals; and (c) intended use of major new chemical production facilities.

3. Declarations. Two types of declarations which might be considered in connexion with chemical weapons prohibitions are:

(a) Declarations Regarding Activities. The Committee might examine the utility of periodic declarations regarding activities relevant to an agreement as one means to help reinforce implementation of an agreement. For example, annual statements by parties, having the effect of affirming their compliance with an agreement, might be considered. The Committee might examine whether declarations which set forth annual national production figures for substances limited by an agreement would offer to parties an additional degree of assurance of continuing observance of an agreement. In the case of a prohibition of nerve-agent production, for example, it would be expected that parties would register zero production or a very small amount destined for scientific research. To emphasize a party's continuing commitment to an agreement, such declarations might be endorsed or issued at the highest governmental level.

(b) Declarations of Facilities. Declarations might also be considered that could be helpful in increasing the effectiveness of various means of verification. For example, submission by parties of lists identifying and locating facilities capable of handling highly toxic materials would be of help in verifying prohibitions of production. What types of facilities might be included in such lists, and whether the lists should contain supplemental information regarding past and present activity at particular installations, could be a subject to be examined within the Committee.

4. Remote Sensing Devices. The question of possible utility of remote sensing devices to detect evidence of CW activity is being studied in various countries. The present level of sensor technology, however, does not appear to offer significant prospects, in the near future, for the development of long-range sensors that could detect evidence of the manufacture or storage of chemical agents. The two principal problems in this respect are the difficulty of achieving sufficiently great sensitivity over large distances and the fact that substances resulting from prohibited and non-prohibited activities may give closely similar readings.

5. Inspection Visits. The Committee should consider possibilities for on-the-scene verification, including such questions as how locations to be visited are chosen and what might be expected to take place during a visit. An on-the-scene inspection by technically qualified personnel may be the most efficient and direct way of resolving a serious question concerning implementation of chemical prohibitions at a given site.

6. Monitoring of Imports and Shipments. Certain chemical substances have limited commercial application. A disproportionate increase in imports or shipments of these materials might be significant in verifying observance of an agreement.

IV. INTERNATIONAL ORGANIZATIONAL CONSIDERATIONS

A number of questions pertaining to international organizational considerations could have possible relation to measures containing prohibitions on chemical weapons. This section discusses (A) possible consultative arrangements, (B) relationship to the Security Council of the United Nations, and (C) the usefulness of provisions for periodic review. The consideration of these questions, as well as those in part V below, would of course be significantly affected by the manner in which questions in the preceding sections, pertaining to scope and to verification, were handled.

A. Consultative Body

In assessing which approaches to the achievement of restraints on chemical weapons are promising and which are not, consideration might be given, at an appropriate stage in the work of the Committee, to whether establishment of a standing consultative body would be helpful and, if so, what its role might be. While recent multilateral arms control agreements have not established or defined special roles for a body of this sort, a consultative group might be able to perform constructive functions in connexion with an agreement on chemical weapons. Given the complexities and difficulties of CW verification problems, provision for a consultative body might offer some additional element of assurance to potential parties to an agreement. Participation in the consultative body of appropriate governmental, military, and scientific representatives might in itself establish increased international confidence, understanding, and co-operation in dealing with problems inherent in the implementation of restraints on CW.

1. Possible Functions.

(a) One function of a consultative body might be to keep abreast, through the participation of appropriate military and scientific experts, with the military potential of various advances in chemistry. Such a function on the part of a consultative body might be particularly relevant if a chemical weapons agreement defined controlled substances using such criteria as a general toxicity standard and/or identification of specific agents. A consultative body might perform the function of reviewing questions regarding new chemical substances and of making such determinations as whether a particular commercially produced substance (i) fell within an agreed toxicity or formula criteria, (ii) should be classified as single-purpose or as dual-purpose, (iii) should be considered a precursor; and whether in light of these assessments the substance should be classified as one controlled or proscribed by the relevant definitions.

(b) Another possible role which might be considered for a consultative body could be in helping to assure parties to a treaty that its provisions were being carried out. Such a body might, for example, be the recipient of reports from parties to a treaty regarding their compliance with its provisions for destruction of existing stocks of lethal chemical agents and chemical weapons. It might also receive information reports on the intended use of organophosphorus substances produced by parties and on the use of certain categories of existing and new chemical production facilities. A consultative body might also receive questions from parties regarding implementation or observance of the CW agreement. In this connexion the consultative body might be the locus for arranging inspection visits to clarify an ambiguous situation and to restore confidence that an agreement was being observed.

2. Organizational Considerations.

(a) Operations. It would be necessary to consider in advance of determining whether to establish a consultative body the way in which it might perform the functions expected of it. Attention would need to be devoted to questions such as the powers that a consultative body might have to initiate actions, to make recommendations, and to solicit the co-operation of parties in the resolution of any problems that might arise. It would also be necessary to consider such practical questions as funding, headquarters, staff, and types of services to be provided. Parties to an agreement would naturally wish to avoid unnecessary costs in implementing any agreements in the CW area and would not wish to establish a new international organization or assign new functions to an existing organization unless substantial benefits could be expected in the solution of problems involved in implementing the agreement.

(b) Membership. The question of membership and participation in such a consultative body would be an important one for potential parties to an agreement. One possibility might be to agree that representatives of all parties to a CW agreement would be entitled to participate in any consultative body concerned with the implementation of that agreement. However, a consultative body might itself determine how experts would be selected for participation in its various activities.

(c) Relationship to Existing Organizations. Since a consultative body might be concerned with a range of issues varying from use of chemical substances for agricultural purposes to questions involving security and political issues, the relationship of such a body to existing international organizations might also be

considered. It might be useful to consider what ties a consultative body would need to have with such offices as the United Nations Secretary-General or with the United Nations Security Council, the United Nations General Assembly, or United Nations specialized agencies, and how these might best be provided for.

B. Relationship to the Security Council

A number of recent arms limitation treaties have contained provisions which specifically recognize the pre-eminent role of the United Nations Security Council in dealing with matters affecting international peace and security. In view of the important security implications any new agreement restricting chemical weapons would have, members of the Committee may wish to consider whether it would be of value to reaffirm in an appropriate manner the right of parties to submit complaints of violation to the Security Council together with all possible evidence, and to set forth an undertaking by parties to co-operate in carrying out any investigations the Security Council might initiate.

C. Review Conference

The Committee might weigh the advantages of a periodic review conference as an additional means of assuring the continued effectiveness of a CW agreement. A review conference could conduct a broad examination of whether the purposes and principles of the agreement were being realized, taking into account particularly any new scientific and technological developments relevant to the agreement. The discussion of issues and problems at a review conference could be of assistance to the subsequent work of any consultative body. Preparations for a review conference could be entrusted to a consultative body, if one had been established.

V. OTHER QUESTIONS

A number of other questions could arise in the course of consideration of possible prohibitions relating to chemical weapons. These might include (A) relationship to the Geneva Protocol, (B) facilitation of international co-operation in the field of peaceful applications, (C) prohibitions of assistance to third parties with respect to proscribed activities, (D) entry into force, (E) duration and withdrawal, and (F) amendments.

A. Relationship to the Geneva Protocol

In connexion with the achievement of any new restrictions on chemical weapons a question will naturally arise as to the relationship between these restrictions and existing restraints in the Geneva Protocol. Committee members may therefore wish to

consider whether any new agreement on chemical weapons should contain provisions noting the importance of the Geneva Protocol and ensuring that nothing in the agreement could be interpreted as in any way limiting or detracting from obligations assumed under the Geneva Protocol.

B. Facilitation of International Co-operation

In view of the fact that restraints on chemical weapons will have an important bearing, directly or indirectly, on activities in peaceful scientific and industrial areas, the Committee may wish to consider whether it would be practical and desirable for any new prohibitions to be accompanied by provisions that make clear the intention of parties to co-operate with other states or international organizations in the further development and peaceful application of science in fields relating to the agreement. Provisions along these lines are contained in both the Biological Weapons Convention and the Treaty on the Non-Proliferation of Nuclear Weapons. It would, therefore, seem logical to consider the desirability of appropriate provisions in the case of restraints on chemical weapons.

C. Assistance to Third Parties

Since parties to any new agreement would be accepting restrictions on their activities, it would seem logical to consider the possibility of appropriate provisions pursuant to which parties would agree not to assist or encourage any others to carry out activities limited by the new agreement. Such provisions, which have been included in recent multilateral arms control agreements, would reinforce the achievement of the broad purposes of any new agreement.

D. Entry Into Force

The question of how additional limitations on chemical weapons enter into force is important because a new agreement would affect weapons of established military significance. The Committee could consider whether a relatively large or a relatively limited number of ratifications ought to be necessary before a new agreement would enter into force. This question could have relationship not only to the possible scope of a new agreement but also to the manner in which questions such as duration and withdrawal are handled.

E. Duration and Withdrawal

The manner in which the questions of duration and withdrawal are handled in any new chemical weapons agreement will have a relationship to the possible scope of any new prohibitions and the extent of reassurance provided to parties through agreed means

of verification. These issues are in turn related to such questions as the overall stability of any new agreement and the extent of capability remaining in the hands of any nation to deter the initiation of chemical warfare by others. Approaches to the question of duration could range from consideration of an agreement limited to a fixed number of years (with possibilities of continuation or renewal), to an agreement of indefinite duration. Intermediate approaches might also be envisioned. Procedures for withdrawal could also vary, in part depending upon whether duration was limited or indefinite.

F. Amendment

Procedures for amendments could assume particular significance in the case of chemical weapons prohibitions. Chemical weapons and agents relate to a field of science and technology which is rapidly expanding and which may undergo basic changes in the future. Thus, technical aspects of prohibitions formulated in the light of technology existing in one decade could be significantly different in another decade. Whether amendments should be relatively easier or more difficult to adopt could also be related to the manner in which the issue of duration was handled.

CONFERENCE OF THE COMMITTEE ON DISARMAMENT

CCD/361

28 March 1972

ENGLISH

Original: RUSSIAN

BULGARIA, CZECHOSLOVAKIA, HUNGARY, MONGOLIA, POLAND,
ROMANIA, UNION OF SOVIET SOCIALIST REPUBLICS

Draft Convention on the prohibition of the development,
production and stockpiling of chemical weapons
and on their destruction

by

Bulgaria, the Byelorussian Soviet Socialist Republic, Czechoslovakia, Hungary,
Mongolia, Poland, Romania, the Ukrainian Soviet Socialist Republic
and the Union of Soviet Socialist Republics

The States Parties to this Convention,

Determined to act with a view to achieving effective progress towards general and complete disarmament including first of all the prohibition and elimination of all types of weapons of mass destruction -- nuclear, chemical and bacteriological,

Convinced that the prohibition of the development, production and stockpiling of chemical weapons and their elimination, through effective measures, will facilitate the achievement of general and complete disarmament under strict and effective international control,

Convinced of the importance and urgency of eliminating from the arsenals of States, through effective measures, such dangerous weapons of mass destruction as those using chemical agents,

Recalling that the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction affirms the recognized objective of effective prohibition of chemical weapons,

Recognizing the important significance of the Geneva Protocol of 17 June 1925 for the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare, and also the contribution which the said Protocol has already made, and continues to make, to mitigating the horrors of war,

Reaffirming their adherence to the principles and objectives of that Protocol and calling upon all States to comply strictly with them,

Recalling that the General Assembly of the United Nations has repeatedly, and particularly in resolution 2827A(XXVI) of 16 December 1971, condemned all actions contrary to the principles and objectives of the Geneva Protocol of 17 June 1925,

Desiring to contribute to the strengthening of confidence between peoples and the general improvement of the international atmosphere,

Desiring also to contribute to the realization of the purposes and principles of the Charter of the United Nations,

Determined, for the sake of all mankind, to exclude completely the possibility of chemical agents being used as weapons,

Convinced that such use would be repugnant to the conscience of mankind and that no effort should be spared to minimize this risk,

Have agreed as follows:

ARTICLE I

Each State Party to this Convention undertakes never in any circumstances to develop, produce, stockpile or otherwise acquire or retain:

- (1) Chemical agents of types and in quantities that have no justification for peaceful purposes;
- (2) Weapons, equipment or means of delivery designed to use such agents for hostile purposes or in armed conflict.

ARTICLE II

Each State Party to this Convention undertakes to destroy, or to divert to peaceful purposes, as soon as possible but not later than months after the entry into force of the Convention, all chemical agents, weapons, equipment and means of delivery specified in Article I of the Convention which are in its possession or under its jurisdiction or control. In implementing the provisions of this Article all necessary safety precautions shall be observed to protect populations and the environment.

ARTICLE III

Each State Party to this Convention undertakes not to transfer to any recipient whatsoever, directly or indirectly, and not in any way to assist, encourage, or induce any State, group of States or international organizations to manufacture or otherwise acquire any of the agents, weapons, equipment or means of delivery specified in Article I of the Convention.

ARTICLE IV

Each State Party to this Convention shall, in accordance with its constitutional processes, take any necessary measures to prohibit and prevent development, production, stockpiling, acquisition or retention of the agents, weapons, equipment and means of delivery specified in Article I of the Convention, within the territory of such State, under its jurisdiction or under its control anywhere.

ARTICLE V

The States Parties to the Convention undertake to consult one another and to co-operate in solving any problems which may arise in relation to the objective of, or in the application of the provisions of, this Convention. Consultation and co-operation pursuant to this Article may also be undertaken through appropriate international procedures within the framework of the United Nations and in accordance with its Charter.

ARTICLE VI

(1) Any State Party to the Convention which finds that any other State Party is acting in breach of obligations deriving from the provisions of this Convention may lodge a complaint with the Security Council of the United Nations. Such a complaint should include all possible evidence confirming its validity, as well as a request for its consideration by the Security Council.

(2) Each State Party to the Convention undertakes to co-operate in carrying out any investigation which the Security Council may initiate, in accordance with the provisions of the United Nations Charter, on the basis of the complaint received by the Council. The Security Council shall inform the States Parties to the Convention of the results of the investigation.

ARTICLE VII

Each State Party to the Convention undertakes to provide or support assistance, in accordance with the United Nations Charter, to any Party to the Convention which so requests, if the Security Council decides that such Party has been exposed to danger as a result of violation of this Convention.

ARTICLE VIII

Nothing in this Convention shall be interpreted as in any way limiting or detracting from the obligations assumed by any State under the Geneva Protocol of 17 June 1925 for the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare, as well as under the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction.

ARTICLE IX

(1) The States Parties to the Convention undertake to facilitate, and have the right to participate in, the fullest possible exchange of equipment, materials and scientific and technological information for the use of chemical agents for peaceful purposes. Parties to the Convention in a position to do so shall also co-operate in contributing individually or together with other States or international organizations to the further development and application of scientific discoveries in the field of chemistry for peaceful purposes.

(2) This Convention shall be implemented in a manner designed to avoid hampering the economic or technological development of States Parties to the Convention or international co-operation in the field of peaceful chemical activities, including the international exchange of chemical agents and equipment for the processing, use or production of chemical agents for peaceful purposes in accordance with the provisions of this Convention.

ARTICLE X

Any State Party may propose amendments to this Convention. Amendments shall enter into force for each State Party accepting the amendments upon their acceptance by a majority of the States Parties to the Convention and thereafter for each remaining State Party on the date of acceptance by it of the amendments.

ARTICLE XI

Five years after the entry into force of this Convention, or earlier if it is requested by a majority of Parties to the Convention by submitting a proposal to this effect to the Depositary Governments, a conference of States Parties to the Convention shall be held at Geneva, Switzerland, to review the operation of this Convention, with a view to assuring that the purposes of the preamble and the provisions of the Convention are being realized. Such review shall take into account any new scientific and technological developments relevant to this Convention.

ARTICLE XII

(1) This Convention shall be of unlimited duration.

(2) Each State Party to this Convention shall in exercising its national sovereignty have the right to withdraw from the Convention if it decides that extraordinary events, related to the subject matter of this Convention, have jeopardized the supreme interests of its country. It shall give notice of such withdrawal to all other States Parties to the Convention and to the United Nations Security Council three months in advance. Such notice shall include a statement of the extraordinary events it regards as having jeopardized its supreme interests.

ARTICLE XIII

(1) This Convention shall be open to all States for signature. Any State which does not sign the Convention before its entry into force in accordance with paragraph (3) of this Article may accede to it at any time.

(2) This Convention shall be subject to ratification by signatory States. Instruments of ratification and instruments of accession shall be deposited with the Governments of _____ which are hereby designated the Depositary Governments.

(3) This Convention shall enter into force after the deposit of the instruments of ratification by _____ Governments, including the Governments designated as Depositaries of the Convention.

(4) For States whose instruments of ratification or accession are deposited subsequent to the entry into force of this Convention, it shall enter into force on the date of the deposit of their instruments of ratification or accession.

(5) The Depositary Governments shall promptly inform all signatory and acceding States of the date of each signature, the date of deposit of each instrument of ratification or of accession and the date of the entry into force of this Convention, and of the receipt of other notices.

(6) This Convention shall be registered by the Depositary Governments pursuant to Article 102 of the Charter of the United Nations.

ARTICLE XIV

This Convention, the Chinese, English, French, Russian and Spanish texts of which are equally authentic, shall be deposited in the archives of the Depositary Governments. Duly certified copies of this Convention shall be transmitted by the Depositary Governments to the Governments of the signatory and acceding States.

In witness whereof the undersigned, duly authorized, have signed this Convention.

Done in _____ copies at _____,
this _____ day of _____, _____.

CONFERENCE OF THE COMMITTEE ON DISARMAMENT

CCD/362

6 April 1972

ENGLISH

Original: RUSSIAN

UNION OF SOVIET SOCIALIST REPUBLICS

Letter dated 6 April 1972 from the Representative of the
Union of Soviet Socialist Republics to the Special
Representative of the Secretary-General of the United Nations

The Ministry of Foreign Affairs of the German Democratic Republic has transmitted to the delegation of the USSR to the Committee on Disarmament a Statement by the Government of the German Democratic Republic with the request that this Statement be brought to the attention of all States members of the Committee. The Statement outlines the position of the German Democratic Republic on problems of disarmament which are being discussed by the Committee.

I should be grateful if you would arrange for the Secretariat of the Committee to circulate my letter, with the attached Statement by the Government of the German Democratic Republic, as an official document of the Conference of the Committee on Disarmament.

(signed) A. ROSHCIN
Representative of the USSR in the
Committee on Disarmament

GE.72-4811

72-11604

STATEMENT BY THE GOVERNMENT OF THE GERMAN DEMOCRATIC REPUBLIC
TO THE COMMITTEE ON DISARMAMENT

I.

The Government of the German Democratic Republic highly appreciates the efforts of the Conference of the Committee on Disarmament to reach agreement on practical and effective measures of arms limitation and disarmament. The Government of the German Democratic Republic proceeds from the standpoint that the arms race is increasing the danger of armed conflicts and is devouring more and more resources which could be better used for improving the well-being of the peoples. The most important problems which must be solved in the interest of peace and security are the ending of the arms race -- particularly in the field of weapons of mass destruction -- and also the elimination of these weapons. As a result of initiatives taken mainly by the Soviet Union and the States allied to it, the Committee on Disarmament has been able to draft a number of agreements on arms limitation and disarmament, to which many States have subsequently acceded. The German Democratic Republic has signed and ratified all these agreements without delay.

The treaties submitted by the Committee on Disarmament are proof that this Committee is doing valuable and useful work. This body has acquired significant experience in considering and solving complex problems of disarmament, and this experience will be of advantage in the elaboration of further measures in this field.

The Government of the German Democratic Republic considers that, in addition to the well-tried forms of considering disarmament problems, new ways and means should be found in order to bring mankind closer to the objective of general and complete disarmament. For this reason the Government of the German Democratic Republic welcomes the fact that, at the twenty-sixth session of the General Assembly of the United Nations, resolution 2833 (XXVI) on the convening of a world disarmament conference received general support. Such a conference could serve to unite the efforts of States aimed at arms limitation and disarmament. It could also give new impetus to the work of the Committee on Disarmament. The German Democratic Republic has from the very outset supported the initiative of the USSR for convening a world disarmament conference. It will work actively for the convening of this conference as soon as possible, and will help to ensure its success.

II.

The Government of the German Democratic Republic has noted with satisfaction that the draft convention on prohibition of the development, production and stockpiling of bacteriological (biological) and toxin weapons and on their destruction, elaborated by the Committee on Disarmament in 1971, met with approval at the twenty-sixth session of

the General Assembly of the United Nations. This Convention creates the prerequisites for eliminating bacteriological and toxin weapons from the arsenals of States once and for all. In addition, it emphasizes the significance of the prohibition of the use of bacteriological and chemical weapons laid down in the Geneva Protocol of 1925.

The Government of the German Democratic Republic considers that the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological and Toxin Weapons and on their Destruction is also a first step on the way to the prohibition of chemical weapons. It welcomes the undertaking, contained in this Convention, to continue negotiations with a view to effective prohibition of chemical weapons. The Government of the German Democratic Republic therefore supports the draft convention submitted by the USSR and other States members of the Warsaw Treaty, and also by the Mongolian People's Republic, on prohibition of the development, production and stockpiling of chemical weapons and on their destruction. The prohibition of chemical weapons, as provided for in this draft convention, is fully in keeping with the interests of the peoples and the appeals of the United Nations.

III.

The Government of the German Democratic Republic advocates the prohibition of all nuclear weapon tests, and the participation of all nuclear weapon States in such a prohibition. It is prepared to accede to a treaty on the prohibition of underground nuclear weapon tests and, within the scope of such a treaty, to participate on a voluntary basis in the exchange of seismic data. It believes that compliance with the relevant treaty obligations can be guaranteed by national means of detection.

The Government of the German Democratic Republic also shares the opinion expressed by the Secretary-General of the United Nations, Dr. Kurt Waldheim, that all the technical and scientific aspects of the prohibition of underground nuclear weapon tests have been so fully explored that only a political decision is now necessary to achieve final agreement on a treaty to this effect. The Government of the German Democratic Republic opposes the attempts by certain States to avoid this political decision.

The efforts of States should be directed towards the elaboration of new agreements on arms limitation and disarmament, and also towards achieving universal effectiveness for the treaties already existing in this field. It is of special importance that the Treaty on the Non-Proliferation of Nuclear Weapons should be universally implemented -- also by such States as the Federal Republic of Germany, Japan, Israel and the Republic of South Africa, which possess the material, scientific and technological potential to produce nuclear weapons.

The Government of the German Democratic Republic, for its part, has done everything to comply with its obligations under this Treaty. For the German Democratic Republic, the Treaty on the Non-Proliferation of Nuclear Weapons has been in force since 5 March 1970. The safeguards agreement between the German Democratic Republic and the International Atomic Energy Agency, as provided for in article III of this Treaty, was signed on 7 March 1972.

The Government of the German Democratic Republic pledges that it will continue in future to follow with due attention the activities of the Committee on Disarmament, and will actively work for the achievement of practical measures of arms limitation and disarmament. It hopes that the Committee on Disarmament will make progress on the road towards general and complete disarmament in the interests of peace and the security of peoples.

CONFERENCE OF THE COMMITTEE ON DISARMAMENT

CCD/363
25 April 1972
Original: ENGLISH

UNITED KINGDOM

Working paper on seismic yields of underground explosions - estimating yields of underground explosions from amplitudes of seismic signals

Definition of Yield and Magnitude

By making seismic measurements close to an explosion in a previously calibrated area, the energy release (size) of the explosion can be estimated. Such estimates of explosion size are generally referred to as the "seismic" yield of the explosion and are expressed in terms of kilotons. Recent testimony before the United States Joint Committee of the AEC suggests that yields of nuclear explosions in the Nevada Test Site can be estimated from such measurements to within 15 to 20 per cent of the yields estimated from radiochemical measurements.

In the context of the comprehensive nuclear test ban (CTB) discussions, the Conference of the Committee on Disarmament (CCD) has been concerned with the more difficult problem of estimating yields of nuclear explosions from seismic waves which have traversed uncalibrated paths of much greater length. A brief recapitulation of the principles involved may be convenient. A small part of the energy released by underground explosions is converted to elastic energy and transmitted to distant parts of the earth as seismic waves. From the amplitudes of these waves, seismologists can determine a "seismic magnitude" for the explosion using magnitude scales devised to measure the relative size of earthquakes. The amplitudes of the seismic waves cannot be used directly as a measure of the size of a seismic event because the recorded amplitude depends on the distance of the recording station from the explosion: in general, the greater the distance the smaller the recorded signal. In computing the magnitude, a factor is applied to the recorded amplitude to correct for the effects of

distance, after which all recording stations ideally give the same magnitude for a given event regardless of distance from the source of the event.

In this working paper we discuss the relationship between the seismic magnitude scales and explosion yields and demonstrate some of the difficulties in arriving at a consistent relationship, and hence in relating the detection and identification thresholds, expressed as magnitudes, of a given recording system to explosion yields.

When the CTB discussions began in 1958 the problem of estimating the relative sizes of earthquakes from recordings at distant stations already had a long history of careful experimental work. The principal objective of the research was the provision of universal distance factors and the following section summarizes the development of this work.

The Seismic Magnitude Scales

A scale for measuring the relative sizes of earthquakes was initiated by Dr. Charles Richter at the Californian Institute of Technology some 40 years ago. A local scale was developed for use with events within 600 kilometres of recording stations, particularly in California, in order to eliminate subjective assessments of size by affected populations. The seismic magnitude scale is logarithmic, that is, differences in amplitudes of 10 at a given station from events at similar distances represent differences of one magnitude unit in the size of the events; the larger the number the greater is the size of the event.

Richter's scale turned out to be more successful than had been expected, and attempts were made to extend its usefulness beyond the local seismic problems of California. With Dr. B. Gutenberg, Richter attempted the task using the combined surface waves recorded by two horizontal components. (In those days, sensitive vertical component seismographs could not be built because of technical problems concerned with the length and stability of springs). This still left out deep focus earthquakes which do not generate such large surface waves, so Gutenberg went a step

further and created a magnitude scale based on the amplitudes of long period (low frequency) body waves, including, of course, the first arriving P waves. The results of this work were published in 1945. Finally, in 1956, Gutenberg and Richter published what is called the unified scale which makes use of data from all sources, including short period P waves. The authors used the term m_b to identify unified magnitudes, and it is this scale which has been in common use for CTB discussions since 1958 because for distant events more data for short period than for long period P waves have been available from the Benioff and Willmore vertical component seismographs. In recent years, however, surface (Rayleigh) wave data have been provided by more sensitive long period vertical component seismographs. The value of magnitudes (M_s) derived from them for discriminating between explosions and earthquakes is well known. This paper demonstrates that surface waves are also useful for estimating the yield of explosions.

Data from small events located at great distances were not numerous in the early days of CTB discussions and the various problems arising in these discussions focussed attention much more than before on the relative sizes and numbers of small seismic events. The problem of relating the original magnitude scale for local events (which included a sufficient number of small earthquakes) to the unified scale (which did not) proved difficult to solve during the lifetime of Technical Working Group II at Geneva in 1959. Long period instruments sensitive enough to record surface waves of such small events had not been developed at the time, and the Kirnos instruments of the Soviet Union, though technically ideal for resolving inconsistencies in the body wave magnitude scales, detect only the larger distant events above the seismic noise which is also well recorded by these seismographs. Some of the early difficulties encountered in applying the unified, or as it is now called, the m_b scale to the detailed seismological problems of a CTB remain unresolved insofar as international agreement is concerned, and an Appendix is devoted to the problem in the report of the Conference on Seismic Methods for Monitoring Underground Explosions, SIPRI Stockholm, 1968.

Specific examples of the problem insofar as it relates to estimating seismic yield of explosions are provided below. They are selected (a) from the United Kingdom studies, on the well documented explosions codenamed Gasbuggy, Rulison and Medeo, which were circulated by the United Kingdom Delegation to the CCD in August 1970 and (b) from the explosions on Amchitka Island in the Aleutians, two of which are equally well documented (for example in AWRE Reports O-67/66 of October 1966, and O-47/70 of August 1970), and which provide a useful frame of reference over a wider range of yields. No attempt is made to summarize the whole of the m_b -- Yield data which has accumulated since 1958; this is the subject of a detailed analysis which is being prepared for publication.

The curve which accompanies this paper (Annex A) does, however, summarize the more consistent surface wave magnitude (M_s) -- yield data. The M_s values plotted on this curve have been measured in accordance with the recommendations outlined in the Canadian Working Paper CCD/327 of June 1971, and detailed in a technical paper soon to be published in the Geophysical Journal of the Royal Astronomical Society, London. Some of the data on which the M_s -- yield curve is based are presented in the technical paper (Nature 1971 Vol. 234, pp. 8-9) at Annex B.

m_b - Yield

Commonsense would suggest that m_b values should increase with increasing explosion yield. This idea can be demonstrated experimentally when source to receiver paths are identical, or nearly so, for successive explosions. Take for example the three explosions on Amchitka Island in the Aleutians as recorded at Eskdalemuir in Scotland. (Yield and magnitude values are rounded off to the nearest significant figure in all the following tables).

Table of Yields and Magnitudes for Explosions on Amchitka
Island Recorded at Eskdalemuir

Explosion	Yield (kilotons)	Yield Ratio	Relative Size from Seismic Amplitudes at Eskdalemuir	Seismic Magnitude at Eskdalemuir (m_b)
Longshot	100	1	1	6.2
Milrow	1000	10	$2\frac{1}{2}$	6.6
Cannikin	5000	50	5	6.9

It might also be expected that the seismic amplitudes would increase in the same ratio as the yields, but this is manifestly not true for the Amchitka to Eskdalemuir path for the observed range of yields.

Nevertheless the result fulfils expectations more closely than the following example of two explosions separated by 300 km on the same continent, which were also recorded at Eskdalemuir.

Table of Yields and Magnitudes for Gasbuggy and Rulison
Recorded at Eskdalemuir

Explosion	Yield (kilotons)	Yield Ratio	Relative Size from Seismic Amplitudes at Eskdalemuir (Corrected for distance)	Seismic Magnitude at Eskdalemuir (m_b)
Gasbuggy (New Mexico)	26	1	1 (4)	5.3
Rulison (Colorado)	40	$1\frac{1}{2}$	0.25 (1)	4.7

On the face of it, the smaller explosion has given the larger seismic signal. A special study by the United Kingdom of the signal amplitudes recorded by distant (teleaseismic) stations and omitting the close-in stations of North America, confirms that the result is not a peculiarity of Eskdalemuir: the average figures are, for Gasbuggy, m_b 5.0 and for Rulison m_b 4.9.

The next example is even more remarkable. It compares readings at Eskdalemuir of Rulison in the United States with two chemical explosions (Medeo) in the Alma Ata region of the Soviet Union.

Table of Yields and Magnitudes for Rulison and Medeo
Recorded at Eskdalemuir

Explosion	Yield (kilotons)	Yield Ratio	Relative Size from Seismic Amplitudes at Eskdalemuir (Corrected for distance)	Seismic Magnitude at Eskdalemuir (m_b)
Rulison	40	24	1	4.7
Medeo (1) (Chemical)	1.7	1	2	5.0
Medeo (2)	3.6	2	3	5.2

The relative size of Medeo (1) as estimated from seismic amplitudes was double that of the explosion which was 24 times more powerful.

These are well documented and accurately made observations which cannot be disputed. Since they were made in the real world, the observations must have rational explanations. The explanations, however, are in dispute and have been the subject of much debate in recent years. Some possible explanations are listed in the following paragraphs, but no attempt is made to arrive at degrees of plausibility or priority, nor to make detailed quantitative assessments. These topics are being dealt with at length in the detailed study referred to earlier.

Discussion of m_b - Yield Anomalies

Along with most seismograph systems Eakdalemuir was designed to detect the characteristic band of frequencies in which the seismic energy of small events is radiated. The centre point of this band moves towards lower frequencies as the size of explosions increases, and because for an explosion of one megaton the centre point of the radiated energy lies on a different part of the sensitivity curve than for one of 1 kiloton, the recorded amplitudes may be that much smaller. (The analogy of radiation from the sun is opposite: the human eye cannot perceive beyond the ultra violet and infra-red ends of the light spectrum.) The importance of the effect for estimating magnitude (m_b) of explosions may be uncertain, but its effect in assessing the relative sizes of larger earthquakes is obvious when comparing the m_b values of "standard" (WSSN) stations with those of the wide band Kirnos instruments of the Soviet Union. The Kirnoc also records a great deal of earth noise and has consequently been held to be less useful since the CTB discussion stimulated efforts for the detection of ever smaller events and thereby pushed research teams into recording two narrow samples of the total seismic spectrum. Nowadays there is a much greater understanding of the structure of earth noise, and the means for reducing its effects, and a new look might with advantage be taken at the Kirnos type system, for discrimination problems as well as those of magnitude and yield.

Another source of the observed anomalies may be due to differences in coupling efficiency. The Committee is already aware that media in which nuclear explosives are emplaced can affect the size of the P wave signals by factors of ten or more when comparing coupling efficiency in dry alluvium with that of a massive rock like granite. In the case of Gasbuggy and Rulison the rocks are shale and sandstone (see AWRE Report O-46/70), which though very different types of rock, are seismically not so different from each other as are dry alluvium and granite. The Medeo explosions were designed to move earth rather than generate seismic energy, and were therefore

incompletely contained; and though that gives the results an even more extraordinary aspect, it must be said that the more slowly reacting chemical explosions are more efficient generators of seismic energy than are nuclear explosions; only a factor of about 2 or 3 has ever been suggested, however.

The amplitude of short period P waves is also sensitive to source depth. The depths at which Gasbuggy (1,300 metres) and Rulison (2,574 metres) were buried are unusually large for the yields involved because the experiments were designed for the purpose of improving the flow of natural gas in strata at those depths. (For weapon tests, it is necessary to bury the device only to a depth sufficient for containment of radioactive debris.) This depth would have the effect of increasing the seismic coupling efficiency, but would tend to separate the surface reflected signal away from the direct signal. This would be particularly true of Rulison, for which the surface reflection can be clearly observed arriving some $1\frac{1}{2}$ seconds after the direct P wave at Eskdalemuir (Figures 2 and 3, AWRE Report O-46/70). In the case of Gasbuggy (and all nuclear weapon tests of similar size which were buried at shallower depths) the surface reflection adds to the direct signal and can thereby double the amplitude of the direct signal. The yields of weapons such as Milrow and Cannikin, however, are so large that the depths for full containment of the debris are sufficient to separate the reflected and direct signals, and the magnitudes of both these events may thereby be under-estimated relative to Longshot; factors nearer to 2 than to 10 are involved.

However, possibly the most important cause of m_b anomalies has been revealed in the last twelve months by studies in the United Kingdom, which indicate that there are deep seated geological structures, in areas which are associated with earthquake belts and with mountain ranges, having a greater capacity for absorbing high frequency seismic energy (short period P waves) than the ocean floor and those ancient blocks in the interior of continents known as shields. Such structures may also cause the

P wave radiation to take two or more paths (multi-pathing) just different enough to cause the signals to interfere one with the other at the recording stations. By means of computers, models of these possible structures have been designed and the passage of seismic signals in them have been studied. The results do suggest that the geophysical causes of the more extraordinary anomalies may be found to underlie seismic and recently seismic areas. As explosion seismologists develop techniques for using larger chemical explosions for the study of earth structure, more evidence accumulates to illustrate the effects because the detonations are often in stable, aseismic areas. The most recent example, an explosion of 10 tons in the North Sea, was reported in the journal Nature as having been recorded as far away as Brasilia and Brisbane, and was given a seismic magnitude of m_b 4.8 at Vinta Basin in Utah. The United Kingdom studies predict that explosions in continental shield areas recorded by stations on shields will be assigned m_b magnitudes some two units greater than recordings of the same yield on seismic area to seismic area paths. When the Soviet Union releases more yields of explosions, great progress in this field of research will be possible because of the variety of geologic structures and seismicity in that country.

But, whatever the explanation, the observations of m_b are a matter for concern since one conclusion to which they lead is that it is at present almost impossible to estimate the relative size of explosions from m_b unless they are fired at one site and compared at one station. This is a very serious constraint in the context of a CTB. Whether for counting numbers of earthquakes at a given yield equivalent, or for defining magnitude yield thresholds, a method for estimating the relative sizes of earthquakes and explosions, much less sensitive to source, path, and receiver and which provides for easily evaluated path corrections is highly desirable.

In recent years the United Kingdom has therefore devoted some effort to the study of this problem. The successful development of sensitive long period vertical seismographs by the United States has made possible the accumulation of surface wave data of small events. The principal impact of these data has, of course, been on the $m_b : M_s$ criterion for discriminating between earthquakes and explosions but the United Kingdom has taken another look at the use of surface wave magnitudes (M_s) for estimating yield, and the principal results of this study are reviewed in the final paragraphs of this paper.

M_s - Yield

What has always been attractive about using surface waves for estimating relative size is firstly, that the much larger wavelengths make them less sensitive to the vagaries of geologic structure, so that gross path corrections can be applied on a continent wide basis, (as was amply demonstrated in the Canadian Working Paper) and secondly, that the frequencies of the recorded signals fall within the usual recording band of frequencies of long period seismographs over a much greater range of yield than is the case for the P signals recorded by high gain short period seismographs. Surface wave magnitudes are also preferred because seismographs in the Soviet Union provide almost identical M_s values to those estimated elsewhere. The difficulty in the use of M_s has been that surface waves were recorded only from relatively large events.

The following table gives the surface wave magnitude-yield comparisons for the set of explosions which have been looked at earlier when considering the m_b - yield relationship. The Medeo explosions cannot be included because no surface waves from them have been detected outside the Soviet Union. The surface wave magnitudes have been determined in accordance with the recommendations of the Canadian Working Paper CCD/327.

Table of Yields and Magnitudes (M_s) for Underground
Explosions in the United States

Explosion	Yield (kilotons)	Yield ratio	Relative size from seismic amplitudes (corrected for distance and path according to CCD/327)	Average seismic magnitude (M_s)
Gasbuggy	26	1	1	3.4
Rulison	40	$1\frac{1}{2}$	1.6	3.6
Longshot	100	4	5	4.1
Milrow	1 000	40	60	5.2
Cannikin	5 000	200	200	5.7

It is immediately obvious that the M_s values are much more consistent over the whole range of yields than any of the m_b values listed in the earlier tables, not only in relation to yield, but also from site to site. This very satisfactory result has been confirmed by detailed analysis of all the surface wave data available to the United Kingdom from explosions for which the yields have been announced, by France, the Soviet Union and the United States.

The attached curve at Annex A summarizes the analysis. For completeness, the M_s - yield theoretical curve for atmospheric explosions is also summarized. The theoretical basis for the curve was published in AWRE O-88/70 of November 1970 and is of special interest at lower yields (less than 50 kilotons) because it applies also to underground explosions in dry alluvium or other unconsolidated rocks. The curve for underground explosions applies to containment in any consolidated rock, in any part of the world. The dotted lines, which bracket the solid, show the maximum scatter of the observations used in the analysis. The release of more yield data, together with more refined path corrections is expected to decrease the width of the error bands.

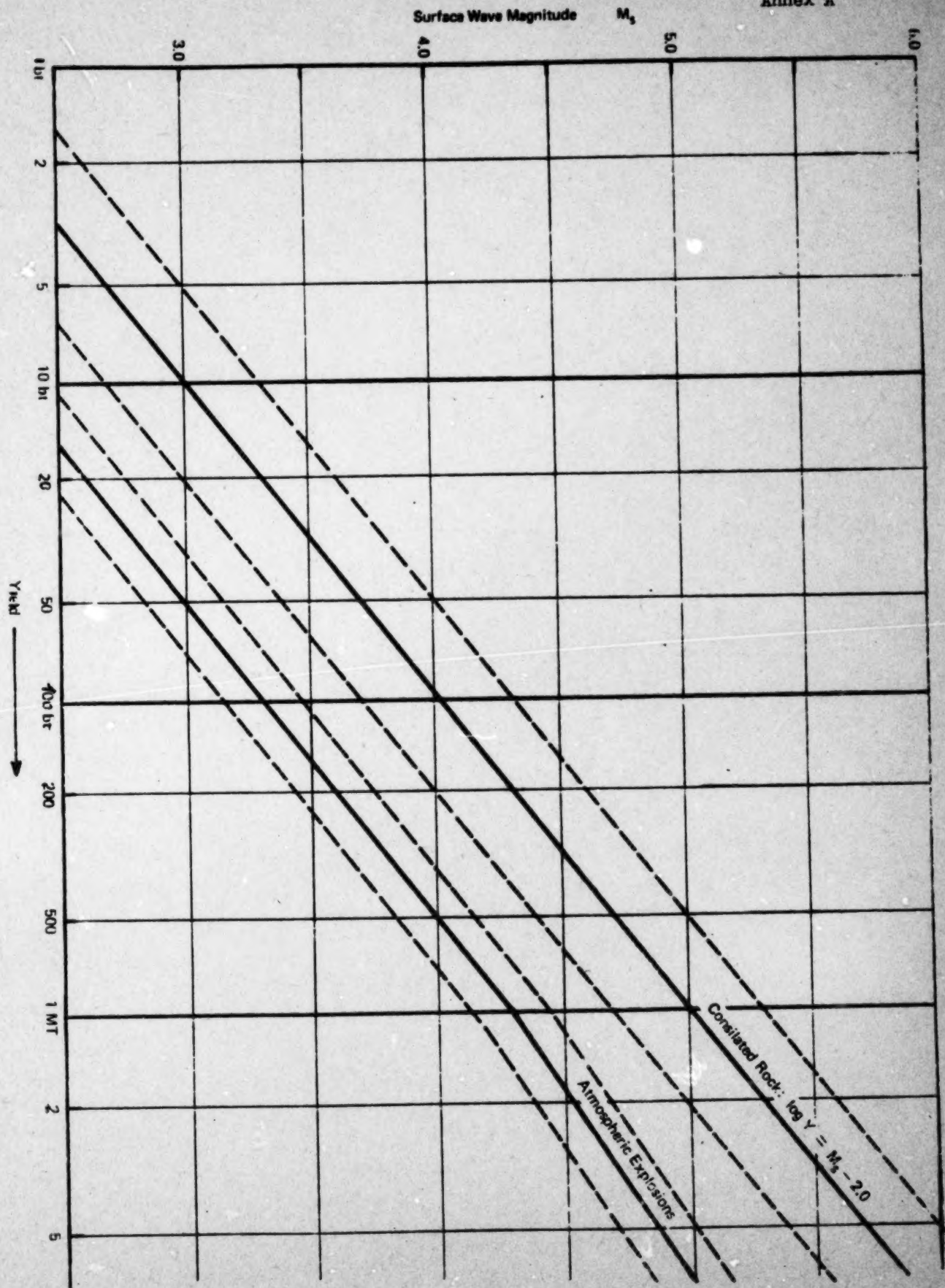
These curves are now used by the United Kingdom for obtaining the best estimates of seismic yield. Low yield explosions, for which surface waves are not detected, must still be estimated from m_b with all their inherent uncertainties, but explosions as small as 5 kilotons have provided surface waves records from the closer stations. As more surface wave data are released, and better long period stations are deployed, the limit of the method will be established, and this limit is also of interest as representing the technical threshold for discrimination by the $m_b:M_s$ criterion.

In using the curves, delegations may find it interesting to make estimates of yield from M_s values provided by their national stations or by world data centres. The path corrections will be found in the technical paper on which the Canadian working paper CCD/327 is based. As an example on which to conclude, the following estimates of the yields of some of the larger underground explosions, which have occurred at each of the world's principal nuclear test sites, are estimated from the path corrected world average M_s values, and the recommended M_s - yield relationship.

Site	Explosion	Average, path corrected M_s	Yield estimates from curve, or $\log Y = M_s - 2(\text{kiloton})$
Sahara	Saphir	4.1	125
Kazakh	13 February 1966	4.4	250
Nevada	Greeley	5.1	1 250
Nevada	Benham	5.1	1 250
Novaya Zemlya	14 October 1970	5.1	1 250
Novaya Zemlya	27 September 1971	5.1	1 250
Aleutian Is	Milrow	5.2	1 600
Aleutian Is	Cannikin	5.7	5 000

Surface wave magnitude-yield curve

CCD/363
Annex A



SURFACE WAVES FROM UNDERGROUND EXPLOSIONS

Several authors^{1,2} have published data on the surface wave magnitude (M_s) and yield (Y) for underground explosions at test sites in North America. Fig. 1 shows the dependence of M_s on yield for all test sites for which we could obtain explosion yield data. The details of the explosions are given in Table 1. From Fig. 1 it is clear that for explosions in consolidated rock (tuff, salt, granite, andesite and sandstone) all the observations lie close to the line

$$M_s = \log Y + 2.0$$

for yields from 4 kton to 1,300 kton. Only for Discus Thrower and Duryea does the observed value of M_s deviate by more than 0.3 magnitude units from this line, so only for these explosions would the yield estimated from M_s differ by more than a factor of 2 from the published yield. For explosions in unconsolidated rock (alluvium) the curve of M_s against yield seems to be more like

$$M_s = \log Y + 1.0$$

at least for yields less than 100 kton, but more data are required to define this curve. The M_s values plotted in Fig. 1 are means of individual station determinations of M_s , each of which is corrected for deviations of the source to receiver path from an

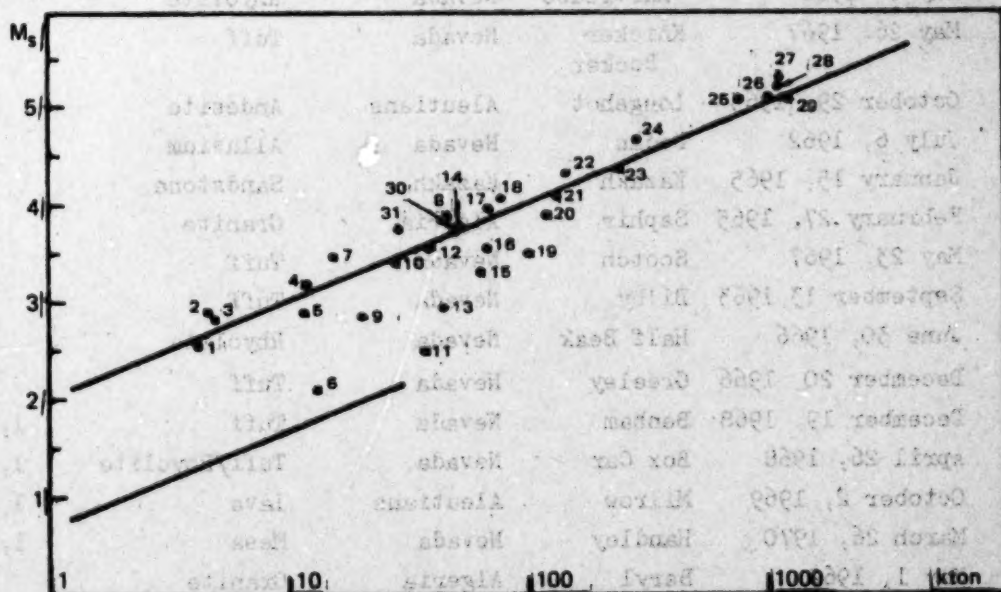


Fig. 1. Surface wave magnitude (M_s) against yield (kton) for explosions in various parts of the world.

Table 1 Details of Some Underground Explosions

Event No.	Date	Name	Region	Medium	Yield(kton)
1	April 14, 1965	Palanquin	Nevada	Rhyolite	4.3 ^{a/}
2	February 15, 1962	Hardhat	Nevada	Granite	4.8 ^{a/}
3	October 22, 1964	Salmon	Mississippi	Salt	5.3 ^{a/}
4	October 26, 1963	Shoal	Nevada	Granite	12.2 ^{a/}
5	November 5, 1964	Handcar	Nevada	Dolomite	12 ^{a/}
6	December 3, 1961	Fisher	Nevada	Alluvium	13.5 ^{a/}
7	February 24, 1966	Rex	Nevada	Tuff	16 ^{a/}
8	September 30, 1966	Bukhara I	Bukhara	Clay	30 ^{f/}
9	May 27, 1966	Discus Thrower	Nevada	Tuff	21 ^{d/}
10	December 10, 1967	Gasbuggy	New Mexico	Shale	29 ^{a/}
11	October 9, 1964	Par	Nevada	Alluvium	38 ^{a/}
12	September 10, 1969	Rulison	Colorado	Shale	40 ^{a/}
13	June 27, 1962	Haymaker	Nevada	Alluvium	45.5 ^{a/}
14	June 2, 1966	Piledriver	Nevada	Granite	56 ^{a/}
15	April 14, 1966	Duryea	Nevada	Rhyolite	65 ^{a/}
16	May 6, 1966	Chartreuse	Nevada	Rhyolite	70 ^{a/}
17	May 26, 1967	Knicker Bocker	Nevada	Tuff	71 ^{a/}
18	October 29, 1965	Longshot	Aleutians	Andesite	85 ^{a/}
19	July 6, 1962	Sedan	Nevada	Alluvium	100 ^{b/}
20	January 15, 1965	Kazakh	Kazakh	Sandstone	125 ^{g/}
21	February 27, 1965	Saphir	Algeria	Granite	135 ^{d/}
22	May 23, 1967	Scotch	Nevada	Tuff	150 ^{a/}
23	September 13, 1963	Bilby	Nevada	Tuff	250 ^{a/}
24	June 30, 1966	Half Beak	Nevada	Rhyolite	300 ^{a/}
25	December 20, 1966	Greeley	Nevada	Tuff	825 ^{a/}
26	December 19, 1968	Benham	Nevada	Tuff	1,100 ^{a/}
27	April 26, 1968	Box Car	Nevada	Tuff/Rhyolite	1,200 ^{a/}
28	October 2, 1969	Milrow	Aleutians	Lava	1,200 ^{e/}
29	March 26, 1970	Handley	Nevada	Mesa	1,200 ^{e/}
30	May 1, 1962	Beryl	Algeria	Granite	52 ^{g/}
31	May 21, 1968	Bukhara II	Bukhara	Salt	47 ^{f/}

^{a/} Ref.10; ^{b/} Vela "Uniform" Information Digest, 2 No.11; ^{c/} inferred from New Scientist, May 19, 437 (1966) and ref.13; ^{d/} ref. 9; ^{e/} press reports; ^{f/} inferred from press reports and ref.11; ^{g/} ref.12.

average path. After correction, the standard deviation (SD) of an observation for a given explosion is usually 0.25 magnitude units and the SD on the mean value of M_s is about 0.1. Corrections are applied for the effect of the path on the propagation of surface waves of different periods. Over short paths in North America, for example, the large amplitude pulse-like arrival observed on wide-band long-period instruments is made up of period components close to a minimum value in the group velocity curve. This apparent large amplitude is due to the path and not to the source; the path effect can be estimated as a function of frequency and a correction determined (P.D.M. and P. Basham, to be published). It should be pointed out that path corrections are significant only for short transmission paths over which there is little dispersion. If these transmission path corrections are not applied, the data do not display a consistent relationship between M_s and yield when data from different test sites are combined.

Theoretical curves of M_s against yield computed using the theory described by Hudson^{3,4} and using the explosion source functions of Haskell⁵ are also shown in Fig.1. These theoretical computations have also been corrected to an average crust. For consolidated rocks, the fit of the computed curve with the observations is very good; for unconsolidated rocks the predicted value of M_s for a given yield seems to be rather low. (Theoretical predictions were only made up to 30 kton in unconsolidated rocks because this is approximately the maximum yield for containment in a surface layer of alluvium 0.5 km thick - the depth of the alluvium layer in the crustal model of the Nevada Test Site⁸).

From the data presented in Fig. 1 we conclude that, provided one assumes that explosions at any location have been fired in consolidated rock, yields can usually be estimated to within a factor of two. This is a great improvement on routine calculations using body wave magnitude. For example, the body wave magnitudes (m_b) of the MEDEO explosions (1.6 kton and 3.7 kton chemical explosions) were 5.0 and 5.2 respectively at Eskdalemuir (EKA)⁷ whereas the value of m_b for the 40 kton Rulison explosion in Colorado was found to be 4.7 at EKA⁸. Fig. 1 also shows that the use of the $m_b:M_s$ criterion⁹ to identify explosions at the teleseismic detection limit of $M_s \sim 2.5$ implied yields of about 40 kton in dry alluvium and 3 kton in consolidated rock. Long period arrays on low noise sites are required to record such low magnitudes at distances greater than 15 degrees from the firing site.

P.D. MARSHALL
A. DOUGLAS

United Kingdom Atomic Energy Authority,
Blacknest, Brimpton, Reading

J.A. HUDSON

Department of Applied Mathematics
and Theoretical Physics,
University of Cambridge

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Working paper on seismic yields of underground explosions - estimating yields of underground explosions from amplitudes of seismic signals

Definition of Yield and Magnitude

By making seismic measurements close to an explosion in a previously calibrated area, the energy release (size) of the explosion can be estimated. Such estimates of explosion size are generally referred to as the "seismic" yield of the explosion and are expressed in terms of kilotons. Recent testimony before the United States Joint Committee of the AEC suggests that yields of nuclear explosions in the Nevada Test Site can be estimated from such measurements to within 15 to 20 per cent of the yields estimated from radiochemical measurements.

In the context of the comprehensive nuclear test ban (CTB) discussions, the Conference of the Committee on Disarmament (CCD) has been concerned with the more difficult problem of estimating yields of nuclear explosions from seismic waves which have traversed uncalibrated paths of much greater length. A brief recapitulation of the principles involved may be convenient. A small part of the energy released by underground explosions is converted to elastic energy and transmitted to distant parts of the earth as seismic waves. From the amplitudes of these waves, seismologists can determine a "seismic magnitude" for the explosion using magnitude scales devised to measure the relative size of earthquakes. The amplitudes of the seismic waves cannot be used directly as a measure of the size of a seismic event because the recorded amplitude depends on the distance of the recording station from the explosion: in general, the greater the distance the smaller the recorded signal. In computing the magnitude, a factor is applied to the recorded amplitude to correct for the effects of

distance, after which all recording stations ideally give the same magnitude for a given event regardless of distance from the source of the event.

In this working paper we discuss the relationship between the seismic magnitude scales and explosion yields and demonstrate some of the difficulties in arriving at a consistent relationship, and hence in relating the detection and identification thresholds, expressed as magnitudes, of a given recording system to explosion yields.

When the CTB discussions began in 1958 the problem of estimating the relative sizes of earthquakes from recordings at distant stations already had a long history of careful experimental work. The principal objective of the research was the provision of universal distance factors and the following section summarizes the development of this work.

The Seismic Magnitude Scales

A scale for measuring the relative sizes of earthquakes was initiated by Dr. Charles Richter at the Californian Institute of Technology some 40 years ago. A local scale was developed for use with events within 600 kilometres of recording stations, particularly in California, in order to eliminate subjective assessments of size by affected populations. The seismic magnitude scale is logarithmic, that is, differences in amplitudes of 10 at a given station from events at similar distances represent differences of one magnitude unit in the size of the events; the larger the number the greater is the size of the event.

Richter's scale turned out to be more successful than had been expected, and attempts were made to extend its usefulness beyond the local seismic problems of California. With Dr. B. Gutenberg, Richter attempted the task using the combined surface waves recorded by two horizontal components. (In those days, sensitive vertical component seismographs could not be built because of technical problems concerned with the length and stability of springs). This still left out deep focus earthquakes which do not generate such large surface waves, so Gutenberg went a step

further and created a magnitude scale based on the amplitudes of long period (low frequency) body waves, including, of course, the first arriving P waves. The results of this work were published in 1945. Finally, in 1956, Gutenberg and Richter published what is called the unified scale which makes use of data from all sources, including short period P waves. The authors used the term m_b to identify unified magnitudes, and it is this scale which has been in common use for CTB discussions since 1958 because for distant events more data for short period than for long period P waves have been available from the Benioff and Willmore vertical component seismographs. In recent years, however, surface (Rayleigh) wave data have been provided by more sensitive long period vertical component seismographs. The value of magnitudes (M_s) derived from them for discriminating between explosions and earthquakes is well known. This paper demonstrates that surface waves are also useful for estimating the yield of explosions.

Data from small events located at great distances were not numerous in the early days of CTB discussions and the various problems arising in these discussions focussed attention much more than before on the relative sizes and numbers of small seismic events. The problem of relating the original magnitude scale for local events (which included a sufficient number of small earthquakes) to the unified scale (which did not) proved difficult to solve during the lifetime of Technical Working Group II at Geneva in 1959. Long period instruments sensitive enough to record surface waves of such small events had not been developed at the time, and the Kirnos instruments of the Soviet Union, though technically ideal for resolving inconsistencies in the body wave magnitude scales, detect only the larger distant events above the seismic noise which is also well recorded by these seismographs. Some of the early difficulties encountered in applying the unified, or as it is now called, the m_b scale to the detailed seismological problems of a CTB remain unresolved insofar as international agreement is concerned, and an Appendix is devoted to the problem in the report of the Conference on Seismic Methods for Monitoring Underground Explosions, SIPRI Stockholm, 1968.

Specific examples of the problem insofar as it relates to estimating seismic yield of explosions are provided below. They are selected (a) from the United Kingdom studies, on the well documented explosions codenamed Gasbuggy, Rulison and Medeo, which were circulated by the United Kingdom Delegation to the CCD in August 1970 and (b) from the explosions on Amchitka Island in the Aleutians, two of which are equally well documented (for example in AWRE Reports O-67/66 of October 1966, and O-47/70 of August 1970), and which provide a useful frame of reference over a wider range of yields. No attempt is made to summarize the whole of the m_b -- Yield data which has accumulated since 1958; this is the subject of a detailed analysis which is being prepared for publication.

The curve which accompanies this paper (Annex A) does, however, summarize the more consistent surface wave magnitude (M_s) -- yield data. The M_s values plotted on this curve have been measured in accordance with the recommendations outlined in the Canadian Working Paper CCD/327 of June 1971, and detailed in a technical paper soon to be published in the Geophysical Journal of the Royal Astronomical Society, London. Some of the data on which the M_s -- yield curve is based are presented in the technical paper (Nature 1971 Vol.234, pp. 8-9) at Annex B.

m_b - Yield

Commonsense would suggest that m_b values should increase with increasing explosion yield. This idea can be demonstrated experimentally when source to receiver paths are identical, or nearly so, for successive explosions. Take for example the three explosions on Amchitka Island in the Aleutians as recorded at Eskdalemuir in Scotland. (Yield and magnitude values are rounded off to the nearest significant figure in all the following tables).

Table of Yields and Magnitudes for Explosions on Amchitka
Island Recorded at Eskdalemuir

Explosion	Yield (kilotons)	Yield Ratio	Relative Size from Seismic Amplitudes at Eskdalemuir	Seismic Magnitude at Eskdalemuir (m_b)
Longshot	100	1	1	6.2
Milrow	1000	10	$2\frac{1}{2}$	6.6
Cannikin	5000	50	5	6.9

It might also be expected that the seismic amplitudes would increase in the same ratio as the yields, but this is manifestly not true for the Amchitka to Eskdalemuir path for the observed range of yields.

Nevertheless the result fulfils expectations more closely than the following example of two explosions separated by 300 km on the same continent, which were also recorded at Eskdalemuir.

Table of Yields and Magnitudes for Gasbuggy and Rulison
Recorded at Eskdalemuir

Explosion	Yield (kilotons)	Yield Ratio	Relative Size from Seismic Amplitudes at Eskdalemuir (Corrected for distance)	Seismic Magnitude at Eskdalemuir (m_b)
Gasbuggy (New Mexico)	26	1	1 (4)	5.3
Rulison (Colorado)	40	$1\frac{1}{2}$	0.25 (1)	4.7

On the face of it, the smaller explosion has given the larger seismic signal. A special study by the United Kingdom of the signal amplitudes recorded by distant (teleaseismic) stations and omitting the close-in stations of North America, confirms that the result is not a peculiarity of Eskdalemuir: the average figures are, for Gasbuggy, m_b 5.0 and for Rulison m_b 4.9.

The next example is even more remarkable. It compares readings at Eskdalemuir of Rulison in the United States with two chemical explosions (Medeo) in the Alma Ata region of the Soviet Union.

Table of Yields and Magnitudes for Rulison and Medeo
Recorded at Eskdalemuir

Explosion	Yield (kilotons)	Yield Ratio	Relative Size from Seismic Amplitudes at Eskdalemuir (Corrected for distance)	Seismic Magnitude at Eskdalemuir (m_b)
Rulison	40	24	1	4.7
Medeo (1)				
(Chemical)	1.7	1	2	5.0
Medeo (2)	3.6	2	3	5.2

The relative size of Medeo (1) as estimated from seismic amplitudes was double that of the explosion which was 24 times more powerful.

These are well documented and accurately made observations which cannot be disputed. Since they were made in the real world, the observations must have rational explanations. The explanations, however, are in dispute and have been the subject of much debate in recent years. Some possible explanations are listed in the following paragraphs, but no attempt is made to arrive at degrees of plausibility or priority, nor to make detailed quantitative assessments. These topics are being dealt with at length in the detailed study referred to earlier.

Discussion of m_b - Yield Anomalies

Along with most seismograph systems Eakdalemuir was designed to detect the characteristic band of frequencies in which the seismic energy of small events is radiated. The centre point of this band moves towards lower frequencies as the size of explosions increases, and because for an explosion of one megaton the centre point of the radiated energy lies on a different part of the sensitivity curve than for one of 1 kiloton, the recorded amplitudes may be that much smaller. (The analogy of radiation from the sun is opposite: the human eye cannot perceive beyond the ultra violet and infra-red ends of the light spectrum.) The importance of the effect for estimating magnitude (m_b) of explosions may be uncertain, but its effect in assessing the relative sizes of larger earthquakes is obvious when comparing the m_b values of "standard" (WWSSN) stations with those of the wide band Kirnos instruments of the Soviet Union. The Kirnos also records a great deal of earth noise and has consequently been held to be less useful since the CTB discussion stimulated efforts for the detection of ever smaller events and thereby pushed research teams into recording two narrow samples of the total seismic spectrum. Nowadays there is a much greater understanding of the structure of earth noise, and the means for reducing its effects, and a new look might with advantage be taken at the Kirnos type system, for discrimination problems as well as those of magnitude and yield.

Another source of the observed anomalies may be due to differences in coupling efficiency. The Committee is already aware that media in which nuclear explosives are emplaced can affect the size of the P wave signals by factors of ten or more when comparing coupling efficiency in dry alluvium with that of a massive rock like granite. In the case of Gasbuggy and Rulison the rocks are shale and sandstone (see AWRE Report O-46/70), which though very different types of rock, are seismically not so different from each other as are dry alluvium and granite. The Medeo explosions were designed to move earth rather than generate seismic energy, and were therefore

incompletely contained; and though that gives the results an even more extraordinary aspect, it must be said that the more slowly reacting chemical explosions are more efficient generators of seismic energy than are nuclear explosions; only a factor of about 2 or 3 has ever been suggested, however.

The amplitude of short period P waves is also sensitive to source depth. The depths at which Gasbuggy (1,300 metres) and Rulison (2,574 metres) were buried are unusually large for the yields involved because the experiments were designed for the purpose of improving the flow of natural gas in strata at those depths. (For weapon tests, it is necessary to bury the device only to a depth sufficient for containment of radioactive debris.) This depth would have the effect of increasing the seismic coupling efficiency, but would tend to separate the surface reflected signal away from the direct signal. This would be particularly true of Rulison, for which the surface reflection can be clearly observed arriving some $1\frac{1}{2}$ seconds after the direct P wave at Eskdalemuir (Figures 2 and 3, AWRE Report O-46/70). In the case of Gasbuggy (and all nuclear weapon tests of similar size which were buried at shallower depths) the surface reflection adds to the direct signal and can thereby double the amplitude of the direct signal. The yields of weapons such as Milrow and Cannikin, however, are so large that the depths for full containment of the debris are sufficient to separate the reflected and direct signals, and the magnitudes of both these events may thereby be under-estimated relative to Longshot; factors nearer to 2 than to 10 are involved.

However, possibly the most important cause of m_b anomalies has been revealed in the last twelve months by studies in the United Kingdom, which indicate that there are deep seated geological structures, in areas which are associated with earthquake belts and with mountain ranges, having a greater capacity for absorbing high frequency seismic energy (short period P waves) than the ocean floor and those ancient blocks in the interior of continents known as shields. Such structures may also cause the

P wave radiation to take two or more paths. (multi-pathing) just different enough to cause the signals to interfere one with the other at the recording stations. By means of computers, models of these possible structures have been designed and the passage of seismic signals in them have been studied. The results do suggest that the geophysical causes of the more extraordinary anomalies may be found to underlie seismic and recently seismic areas. As explosion seismologists develop techniques for using larger chemical explosions for the study of earth structure, more evidence accumulates to illustrate the effects because the detonations are often in stable, aseismic areas. The most recent example, an explosion of 10 tons in the North Sea, was reported in the journal Nature as having been recorded as far away as Brasilia and Brisbane, and was given a seismic magnitude of m_b 4.8 at Vinta Basin in Utah. The United Kingdom studies predict that explosions in continental shield areas recorded by stations on shields will be assigned m_b magnitudes some two units greater than recordings of the same yield on seismic area to seismic area paths. When the Soviet Union releases more yields of explosions, great progress in this field of research will be possible because of the variety of geologic structures and seismicity in that country.

But, whatever the explanation, the observations of m_b are a matter for concern since one conclusion to which they lead is that it is at present almost impossible to estimate the relative size of explosions from m_b unless they are fired at one site and compared at one station. This is a very serious constraint in the context of a CTB. Whether for counting numbers of earthquakes at a given yield equivalent, or for defining magnitude yield thresholds, a method for estimating the relative sizes of earthquakes and explosions, much less sensitive to source, path, and receiver and which provides for easily evaluated path corrections is highly desirable.

In recent years the United Kingdom has therefore devoted some effort to the study of this problem. The successful development of sensitive long period vertical seismographs by the United States has made possible the accumulation of surface wave data of small events. The principal impact of these data has, of course, been on the $m_b : M_s$ criterion for discriminating between earthquakes and explosions but the United Kingdom has taken another look at the use of surface wave magnitudes (M_s) for estimating yield, and the principal results of this study are reviewed in the final paragraphs of this paper.

M_s - Yield

What has always been attractive about using surface waves for estimating relative size is firstly, that the much larger wavelengths make them less sensitive to the vagaries of geologic structure, so that gross path corrections can be applied on a continent wide basis, (as was amply demonstrated in the Canadian Working Paper) and secondly, that the frequencies of the recorded signals fall within the usual recording band of frequencies of long period seismographs over a much greater range of yield than is the case for the P signals recorded by high gain short period seismographs. Surface wave magnitudes are also preferred because seismographs in the Soviet Union provide almost identical M_s values to those estimated elsewhere. The difficulty in the use of M_s has been that surface waves were recorded only from relatively large events.

The following table gives the surface wave magnitude-yield comparisons for the set of explosions which have been looked at earlier when considering the m_b - yield relationship. The Medeo explosions cannot be included because no surface waves from them have been detected outside the Soviet Union. The surface wave magnitudes have been determined in accordance with the recommendations of the Canadian Working Paper CCD/327.

Table of Yields and Magnitudes (M_s) for Underground Explosions in the United States

Explosion	Yield (kilotons)	Yield ratio	Relative size from seismic amplitudes (corrected for distance and path according to CCD/327)	Average seismic magnitude (M_s)
Gasbuggy	26	1	1	3.4
Rulison	40	$1\frac{1}{2}$	1.6	3.6
Longshot	100	4	5	4.1
Milrow	1 000	40	60	5.2
Cannikin	5 000	200	200	5.7

It is immediately obvious that the M_s values are much more consistent over the whole range of yields than any of the m_b values listed in the earlier tables, not only in relation to yield, but also from site to site. This very satisfactory result has been confirmed by detailed analysis of all the surface wave data available to the United Kingdom from explosions for which the yields have been announced, by France, the Soviet Union and the United States.

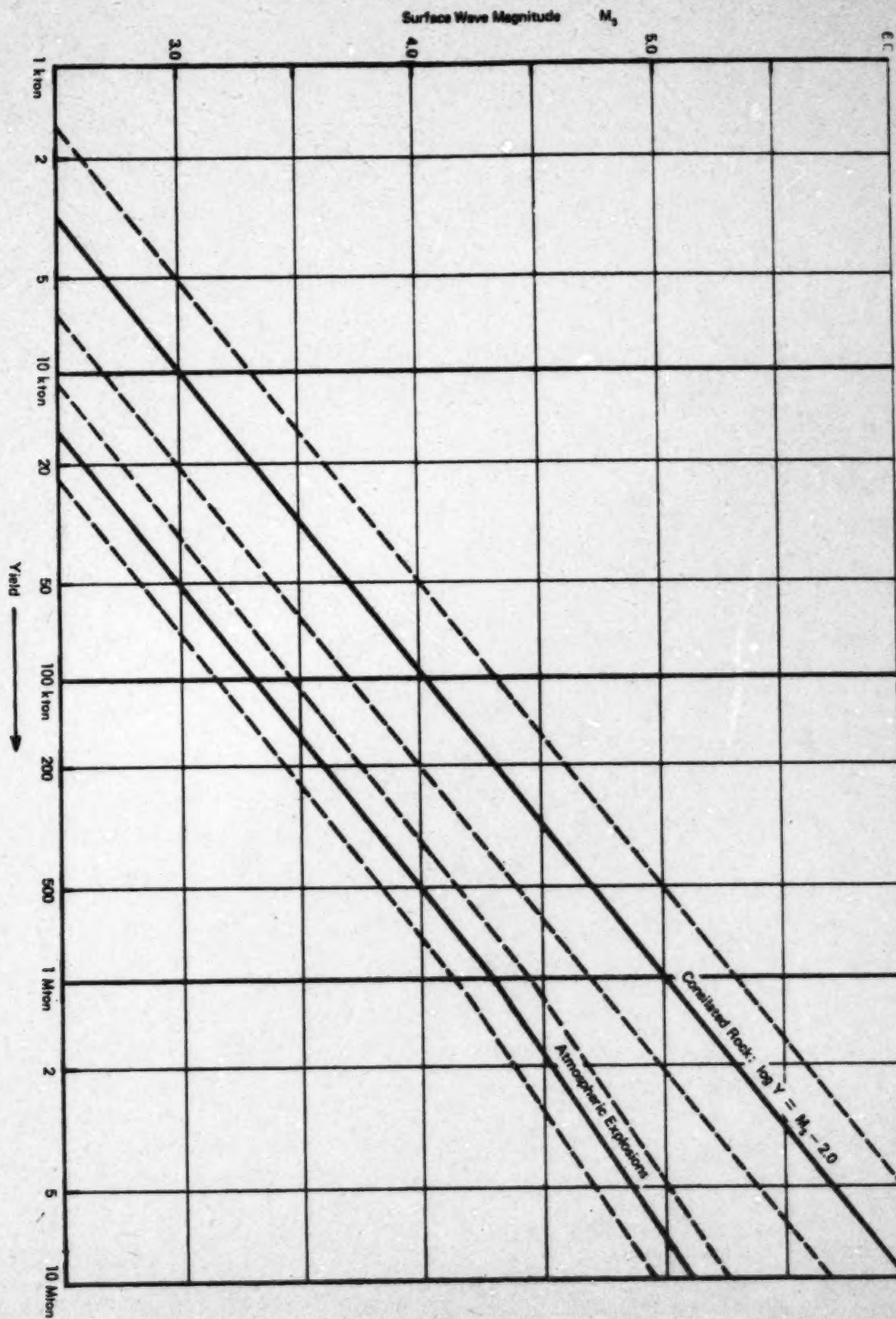
The attached curve at Annex A summarizes the analysis. For completeness, the M_s - yield theoretical curve for atmospheric explosions is also summarized. The theoretical basis for the curve was published in AWRE O-88/70 of November 1970 and is of special interest at lower yields (less than 50 kilotons) because it applies also to underground explosions in dry alluvium or other unconsolidated rocks. The curve for underground explosions applies to containment in any consolidated rock, in any part of the world. The dotted lines, which bracket the solid, show the maximum scatter of the observations used in the analysis. The release of more yield data, together with more refined path corrections is expected to decrease the width of the error bands.

These curves are now used by the United Kingdom for obtaining the best estimates of seismic yield. Low yield explosions, for which surface waves are not detected, must still be estimated from m_b with all their inherent uncertainties, but explosions as small as 5 kilotons have provided surface waves records from the closer stations. As more surface wave data are released, and better long period stations are deployed, the limit of the method will be established, and this limit is also of interest as representing the technical threshold for discrimination by the $m_b:M_s$ criterion.

In using the curves, delegations may find it interesting to make estimates of yield from M_s values provided by their national stations or by world data centres. The path corrections will be found in the technical paper on which the Canadian working paper CCD/327 is based. As an example on which to conclude, the following estimates of the yields of some of the larger underground explosions, which have occurred at each of the world's principal nuclear test sites, are estimated from the path corrected world average M_s values, and the recommended M_s - yield relationship.

Site	Explosion	Average, path corrected M_s	Yield estimates from curve, or $\log Y = M_s - 2(\text{kiloton})$
Sahara	Saphir	4.1	125
Kazakh	13 February 1966	4.4	250
Nevada	Greeley	5.1	1 250
Nevada	Benham	5.1	1 250
Novaya Zemlya	14 October 1970	5.1	1 250
Novaya Zemlya	27 September 1971	5.1	1 250
Aleutian Is	Milrow	5.2	1 600
Aleutian Is	Cannikin	5.7	5 000

Surface wave magnitude-yield curve



SURFACE WAVES FROM UNDERGROUND EXPLOSIONS

Several authors^{1,2} have published data on the surface wave magnitude (M_s) and yield (Y) for underground explosions at test sites in North America. Fig. 1 shows the dependence of M_s on yield for all test sites for which we could obtain explosion yield data. The details of the explosions are given in Table 1. From Fig. 1 it is clear that for explosions in consolidated rock (tuff, salt, granite, andesite and sandstone) all the observations lie close to the line

$$M_s = \log Y + 2.0$$

for yields from 4 kton to 1,300 kton. Only for Discus Thrower and Duryea does the observed value of M_s deviate by more than 0.3 magnitude units from this line, so only for these explosions would the yield estimated from M_s differ by more than a factor of 2 from the published yield. For explosions in unconsolidated rock (alluvium) the curve of M_s against yield seems to be more like

$$M_s = \log Y + 1.0$$

at least for yields less than 100 kton, but more data are required to define this curve. The M_s values plotted in Fig. 1 are means of individual station determinations of M_s , each of which is corrected for deviations of the source to receiver path from an

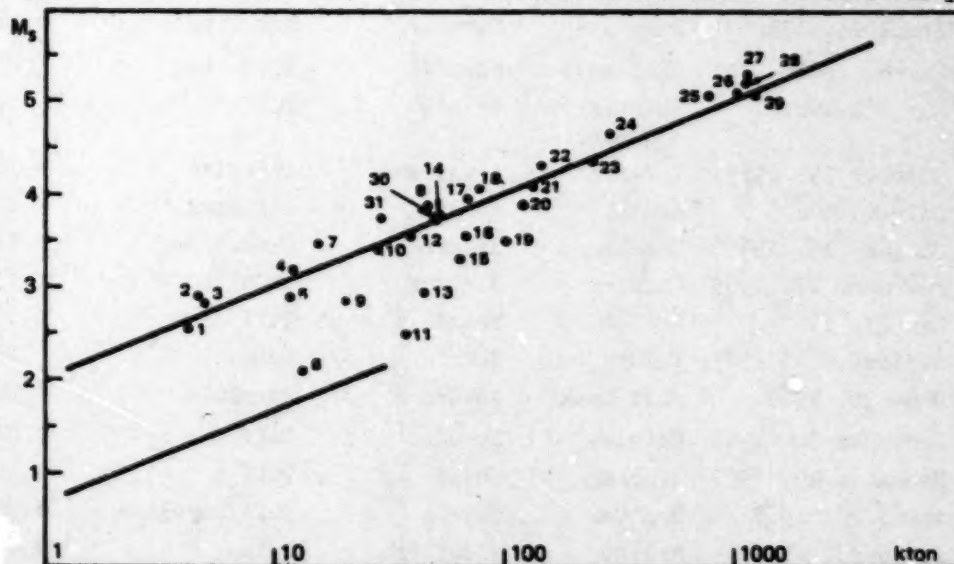


Fig. 1 Surface wave magnitude (M_s) against yield (kton) for explosions in various parts of the world.

Table 1 Details of Some Underground Explosions

Event No.	Date	Name	Region	Medium	Yield(kton)
1	April 14, 1965	Palanquin	Nevada	Rhyolite	4.3 ^{a/}
2	February 15, 1962	Hardhat	Nevada	Granite	4.8 ^{a/}
3	October 22, 1964	Salmon	Mississippi	Salt	5.3 ^{a/}
4	October 26, 1963	Shoal	Nevada	Granite	12.2 ^{a/}
5	November 5, 1964	Handcar	Nevada	Dolomite	12 ^{a/}
6	December 3, 1961	Fisher	Nevada	Alluvium	13.5 ^{a/}
7	February 24, 1966	Rex	Nevada	Tuff	16 ^{a/}
8	September 30, 1966	Bukhara I	Bukhara	Clay	30 ^{f/}
9	May 27, 1966	Discus Thrower	Nevada	Tuff	21 ^{a/}
10	December 10, 1967	Gasbuggy	New Mexico	Shale	29 ^{a/}
11	October 9, 1964	Par	Nevada	Alluvium	38 ^{a/}
12	September 10, 1969	Rulison	Colorado	Shale	40 ^{a/}
13	June 27, 1962	Haymaker	Nevada	Alluvium	45.5 ^{a/}
14	June 2, 1966	Piledriver	Nevada	Granite	56 ^{a/}
15	April 14, 1966	Duryea	Nevada	Rhyolite	65 ^{a/}
16	May 6, 1966	Chartreuse	Nevada	Rhyolite	70 ^{a/}
17	May 26, 1967	Knicker- Bocker	Nevada	Tuff	71 ^{a/}
18	October 29, 1965	Longshot	Aleutians	Andesite	85 ^{a/}
19	July 6, 1962	Sedan	Nevada	Alluvium	100 ^{b/}
20	January 15, 1965	Kazakh	Kazakh	Sandstone	125 ^{c/}
21	February 27, 1965	Saphir	Algeria	Granite	135 ^{d/}
22	May 23, 1967	Scotch	Nevada	Tuff	150 ^{a/}
23	September 13, 1963	Bilby	Nevada	Tuff	250 ^{a/}
24	June 30, 1966	Half Beak	Nevada	Rhyolite	300 ^{a/}
25	December 20, 1966	Greeley	Nevada	Tuff	825 ^{a/}
26	December 19, 1968	Benham	Nevada	Tuff	1,100 ^{a/}
27	April 26, 1968	Box Car	Nevada	Tuff/Rhyolite	1,200 ^{a/}
28	October 2, 1969	Milrow	Aleutians	Lava	1,200 ^{e/}
29	March 26, 1970	Handley	Nevada	Mesa	1,200 ^{e/}
30	May 1, 1962	Beryl	Algeria	Granite	52 ^{g/}
31	May 21, 1968	Bukhara II	Bukhara	Salt	47 ^{f/}

^{a/}Ref.10; ^{b/}Vela "Uniform" Information Digest, 2 No.11; ^{c/}inferred from New Scientist, May 19, 437 (1966) and ref.13; ^{d/}ref. 9; ^{e/}press reports; ^{f/}inferred from press reports and ref.11; ^{g/}ref.12.

average path. After correction, the standard deviation (SD) of an observation for a given explosion is usually 0.25 magnitude units and the SD on the mean value of M_s is about 0.1. Corrections are applied for the effect of the path on the propagation of surface waves of different periods. Over short paths in North America, for example, the large amplitude pulse-like arrival observed on wide-band long-period instruments is made up of period components close to a minimum value in the group velocity curve. This apparent large amplitude is due to the path and not to the source; the path effect can be estimated as a function of frequency and a correction determined (P.D.M. and P. Basham, to be published). It should be pointed out that path corrections are significant only for short transmission paths over which there is little dispersion. If these transmission path corrections are not applied, the data do not display a consistent relationship between M_s and yield when data from different test sites are combined.

Theoretical curves of M_s against yield computed using the theory described by Hudson^{3,4} and using the explosion source functions of Haskell⁵ are also shown in Fig.1. These theoretical computations have also been corrected to an average crust. For consolidated rocks, the fit of the computed curve with the observations is very good; for unconsolidated rocks the predicted value of M_s for a given yield seems to be rather low. (Theoretical predictions were only made up to 30 kton in unconsolidated rocks because this is approximately the maximum yield for containment in a surface layer of alluvium 0.5 km thick - the depth of the alluvium layer in the crustal model of the Nevada Test Site⁶).

From the data presented in Fig. 1 we conclude that, provided one assumes that explosions at any location have been fired in consolidated rock, yields can usually be estimated to within a factor of two. This is a great improvement on routine calculations using body wave magnitude. For example, the body wave magnitudes (m_b) of the MEDEO explosions (1.6 kton and 3.7 kton chemical explosions) were 5.0 and 5.2 respectively at Eskdalemuir (EKA)⁷ whereas the value of m_b for the 40 kton Rulison explosion in Colorado was found to be 4.7 at EKA⁸. Fig. 1 also shows that the use of the $m_b:M_s$ criterion⁹ to identify explosions at the teleseismic detection limit of $M_s \sim 2.5$ implies yields of about 40 kton in dry alluvium and 3 kton in consolidated rock. Long period arrays on low noise sites are required to record such low magnitudes at distances greater than 15 degrees from the firing site.

P.D. MARSHALL
A. DOUGLAS

United Kingdom Atomic Energy Authority,
Blacknest, Brimpton, Reading

J.A. HUDSON

Department of Applied Mathematics
and Theoretical Physics,
University of Cambridge

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